State of California
The Resources Agency
Department of Water Resources

DRAFT
SP-F8: TRANSFER OF ENERGY AND NUTRIENTS BY ANADROMOUS FISH MIGRATIONS

Oroville Facilities Relicensing
FERC Project No. 2100

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REPORT SUMMARY

This report investigates the potential impact of the elimination of anadromous salmonid spawning runs on ecosystem productivity of the historical Feather River tributaries upstream of Lake Oroville. Salmon and steelhead transport nutrients and organic matter accumulated in the ocean upstream to their natal stream during their spawning migrations. These streams typically rely on these marine-derived nutrients for much of their productive capacity. A loss of the salmonids generally results in nutrient-poor conditions. Construction of the Oroville Facilities resulted in the elimination of anadromous salmonids upstream of the Fish Barrier Dam. The loss of Chinook salmon and steelhead from the inundation basin of Lake Oroville is mitigated by the operation of the Feather River Fish Hatchery and other mitigation measures, but the potential loss of marine-derived nutrients to the tributaries upstream of the reservoir has not been mitigated.

The principal objectives of this report are to determine the amount of nutrients and organic matter lost from the upstream tributaries as a result of the elimination of Chinook salmon and steelhead, to evaluate the effect of the losses on productivity of the tributaries, and to assess the need for nutrient mitigation or enhancement measures and potential approaches for implementing such measures. These objectives were only partially satisfied because of gaps in the availability of anticipated data. A range of estimates for the amount of nutrients and organic matter lost was computed, but the range was very broad because it was derived from estimates of potential escapement of anadromous salmonids in the upstream tributaries, and these estimates ranged broadly. The significance of the nutrient and organic matter losses and the need for mitigation could not be determined because data on the current nutrient status of the upstream tributaries are inadequate. However, the report is useful in elucidating the information and analyses required to determine the significance of the nutrient losses. The report also presents a review of potential nutrient enhancement and mitigation measures that will be valuable in guiding the development of potential future PM&Es addressing the nutrient conditions in the tributaries.

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1.0 INTRODUCTION

Ecological studies of Pacific salmon illustrate the importance of the anadromous salmonids in the transport of nutrients and organic matter to the freshwater aquatic ecosystems where they spawn. Preying and scavenging by terrestrial organisms on the salmonids, eggs, and carcasses, and other ecosystem processes result in the enrichment of terrestrial habitats as well (Cederholm et al. 1999; Gresh et al., 2000; Bilby et al. 2001).

The construction of the Fish Barrier Dam, the Thermalito Diversion Dam, and Oroville Dam (herein collectively called the Oroville Facilities) prevents the migration of Chinook salmon and steelhead to the historical spawning grounds in the tributaries of the Feather River located upstream of Lake Oroville (also called the upstream tributaries). This results in the removal of the salmonids as a source of energy and nutrients in these habitats and potentially reduces the productivity of the aquatic and terrestrial ecosystems.

This study is designed to address the effects of the Oroville Facilities on the nutrient and organic matter transfers to the upstream tributaries. Historical nutrient and organic matter transfers are estimated from escapement estimates for the upstream tributaries and estimates of salmonid nutrient and organic matter content derived from previous studies. To this end, escapement estimates for the upstream tributaries were developed based on two separate methodologies. First, historical escapement surveys for the upstream tributaries were reviewed to provide estimates of the number of salmon contributing to the upstream transfer of nutrients and organic matter prior to the construction of the Oroville Facilities. Second, potential escapement estimates were developed based on the current available salmonid spawning habitat in the upstream tributaries and observed Chinook salmon spawning densities in the spawning grounds of several rivers, including the Feather River downstream of Lake Oroville. Neither escapement estimate is designed to definitively determine the nutrients lacking from the upstream tributaries, but instead is designed to provide a range of estimates and baseline information useful for facilitating a dialog regarding appropriate nutrient mitigation techniques for the upper tributary environments.

The purpose of this study is to collect baseline information to evaluate the effect of ongoing blockage of the upstream transfer of salmonid-derived nutrients and organic matter to the upstream tributaries. The resulting information will be used to develop and evaluate potential future PM&Es.

The remainder of this report is organized as described in the following. Section 1 provides various background information to elucidate the scientific, regulatory, geographic, historical, and project-operations context of the study. The section includes a review of the scientific literature concerning nutrient sources, nutrient cycling and food webs in western North American stream ecosystems to provide a context for understanding the potential significance of salmonid transfers of nutrients and organic matter. Section 2 explains the need for the study and Section 3 presents the study objectives. Section 4 describes the methodology for the study, including the overall study design and specific procedures fro each of four principal study tasks. Section 5 presents gives the study results, broken down by study task. Section 5.1 presents historical information on the distribution and abundance of adult salmon and steelhead in the upstream tributaries prior to the construction of the Oroville Facilities. Section 5.2 develops estimates of potential escapement for the upstream tributaries by combining recent estimates of spawning density in the Feather River downstream of the Oroville Facilities and in other Pacific salmon streams with estimates of current salmonid spawning habitat in the upstream tributaries. Section 5.3 combines information on nutrient and organic matter content of salmon with the escapement estimates from Section 5.2 to develop a range of estimates for nutrient and organic matter excluded from the upstream tributaries by the Oroville Facilities. Section 5.4 discusses mitigation and enhancement programs that have been proposed for and/or adopted in other river basins to replenish nutrients and organic matter where natural salmonid spawning has declined. Section 6.0 summarizes the study conclusions and Section 7.0 lists the references cited in the report.

1.1 BACKGROUND INFORMATION

1.1.1 Statutory/Regulatory Requirements

This study is needed because project facilities currently prevent the upstream movement of anadromous fish stocks and may therefore potentially affect the transfer of marine-derived nutrients and organic matter to the tributaries upstream of Lake Oroville. This potential reduction of nutrient transfers may contribute to a general decrease in productivity in the aquatic and terrestrial ecosystems of the upstream tributary basins. However, focused studies on the Feather River investigating the relationship between blockage of anadromous salmonid passage and nutrient and organic material levels in the upstream tributaries have never been conducted.

The potential loss of ecological productivity due to the elimination of the anadromous Chinook salmon and steelhead runs from the Feather River Basin upstream of Oroville Dam represents a continuing impact of the project on the biological resources of the area. Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the FERC Application for License for major hydropower projects, including a discussion of the fish, wildlife and botanical resources in the vicinity of the project. The discussion needs to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operation of the project. In addition to fulfilling these requirements, the specific investigations developed in this study plan will also be used in determining PM&E measures.

1.1.2 Study Area

Four major tributaries exist upstream of the Oroville Facilities including the North Fork Feather River, the West Branch of the North Fork Feather River, the Middle Fork Feather River, and the South Fork Feather River (Figure 1.1-1). Smaller tributaries in the upstream drainages include Berry Creek, Canyon Creek, Chino Creek, Concow Creek, Fall River, French Creek, Frey Creek, Sucker Run Creek, McCabe Creek and Stony Creek. The study area is defined as Lake Oroville and its tributaries upstream to the first salmonid migration barrier in each tributary (Figure 1.1-1). Upstream migration barriers have not been determined for Canyon Creek, Concow Creek, Fall Creek, French Creek, Frey Creek and McCabe Creek, so portions of these tributaries upstream of the reservoir inundation zone are not included in the study area.

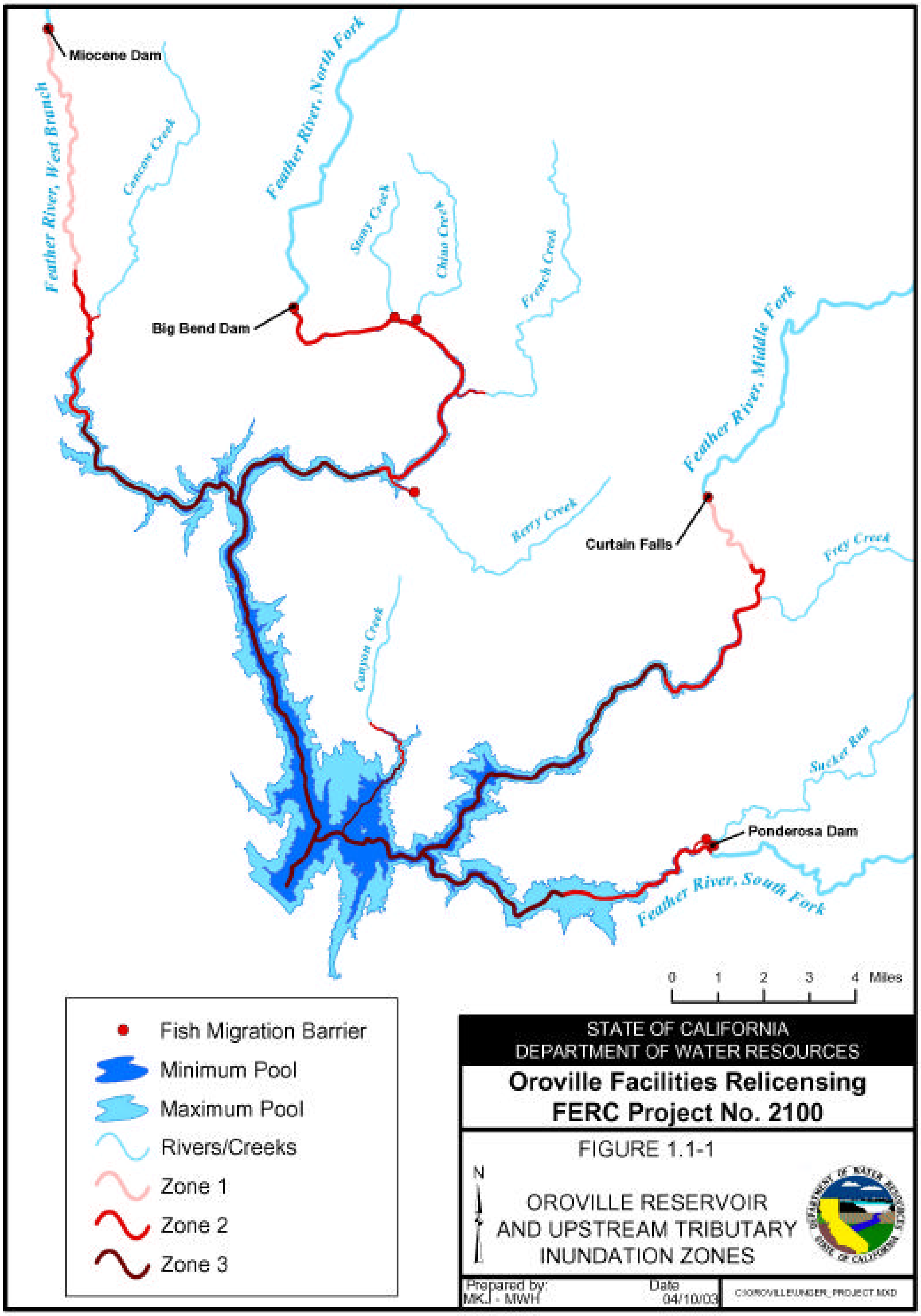
As shown in Figure 1.1-1, three inundation zones can be distinguished for the tributaries: Zone 1 includes all tributary reaches that are never inundated by Lake Oroville (i.e., between reservoir maximum pool level and the first migration barrier), Zone 2 includes all tributary reaches that are in the fluctuation zone of the reservoir (i.e., between reservoir levels at minimum and maximum pool), and Zone 3 includes all tributary reaches that are permanently inundated by the reservoir (i.e., below minimum pool). Zone 1 is absent from the North and South Forks of the Feather River and largely absent from the smaller tributaries because the first migration barriers on these streams are below the level of the reservoir at maximum pool (Figure 1.1-1).

The focus of this study is on the Zone 1 tributary reaches because these reaches maintain stream ecosystem functions and provide salmonid spawning habitat throughout the year. The need for nutrient enhancement in Zones 2 and 3 is difficult to evaluate because these tributary reaches are intermittently or permanently inundated by Lake Oroville and, therefore, are subject to the reservoir's nutrient budget, which is poorly understood. Zones 2 and 3 are included in the study to assess the total amount of salmonid escapement affected by the Oroville Facilities and total amount of nutrients and organic matter represented by this escapement.

1.1.3 Review of Nutrient Sources and Cycling in Stream Ecosystems and the Role of Anadromous Salmonids

1.1.3.1 Nutrient Sources and Cycling in Streams

Organic matter in streams is either produced within the stream or it originates elsewhere and falls or is transported into the stream. Organic matter produced within the stream is termed autochthonous, whereas matter originating from outside the stream is termed allocthonous. Autochthonous material is photosynthesized by algae or vascular plants using sunlight and inorganic materials in the stream, whereas allocthonous material is typically produced by terrestrial plants and enters the stream via litterfall, runoff and terrestrial animals that die or defecate in the stream. Since photosynthesis requires


Miocene Dam
Feather River, West Branch
Concow Creek
Feather River, North Fork
Stony Creek
Chino Creek
French Creek
Big Bend Dam
Feather River, Middle Fork
Berry Creek
Curtain Falls
Frey Creek
Canyon Creek
Sucker Run
Ponderosa Dam
Feather River, South Fork
0 1 2 3 4 Miles
Fish Migration Barrier
Minimum Pool
Maximum Pool
Rivers/Creeks
Zone 1
Zone 2
Zone 3
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
Oroville Facilities Relicensing
FERC Project No. 2100
FIGURE 1.1-1
N
OROVILLE RESERVOIR
AND UPSTREAM TRIBUTARY
INUNDATION ZONES
Prepared by:
MKJ - MWH
Date
04/10/03

sunlight, autochthonous organic matter is generally more important in larger, more exposed streams, while allochthonous organic matter often dominates small streams that are heavily shaded by, and receive large amounts of litterfall from, riparian vegetation. Recent studies have identified anadromous fishes as another important source of allochthonous organic matter in some streams. Nearly all of the organic matter in most anadromous fishes, such as Pacific salmon, derives ultimately from marine algae and is transported to the streams by adult salmon migrating upstream to spawn. Allochthonous material from migrating salmon will be discussed in the next section.

The production of organic matter by photosynthesis requires a number of important elements. Carbon, hydrogen and oxygen are the principal constituents of organic matter, but these elements are generally in plentiful supply in streams as carbon dioxide and water. Nitrogen and phosphorus are also essential for photosynthesis, but their supply is often limited. Free nitrogen is plentiful in the air, but only blue-green algae and a few types of bacteria are able to fix (incorporate) this form of nitrogen and, therefore, most nitrogen used by plants comes from organic matter that has been decomposed by bacteria and/or fungi. Phosphorus originates from the weathering of certain types of rock, but as for nitrogen, much of the phosphorus used by plants comes from decomposed organic matter. Because nitrogen and phosphorus are the essential nutrients that are most often in short supply in ecosystems, their supply, together with sunlight and temperature, most often determines an ecosystem's productivity. However, because stream ecosystems often derive most of their organic matter and nutrients from outside sources, they may be productive even when sunlight is limited.

Once organic matter has been photosynthesized within a stream, or has entered the stream from outside, heterotrophic pathways of the stream ecosystem begin assimilating it (Bisson and Bilby 2001). The organic matter provides both the energy and the mineral nutrient requirements of heterotrophic organisms in the stream, including bacteria, fungi, invertebrates, and fishes and other vertebrates. Leaves and other allochthonous material in a stream are rapidly colonized by bacteria and fungi, which consume dissolved organic matter leached from the leaves. These microbes form an organic matrix over the leaf surface, which is inhabited by microscopic animals and early instars of macroinvertebrates, including insects. Autochthonous dead plant and animal material is generally processed in the same way. Layers of organic matter, known as biofilm, also form on stones in the streambed and in the hyporheic zone, extracting dissolved organic matter from the water (Bilby et al. 1996, Wipfli et al. 1998). Larger macroinvertebrates consume the dead plant material, deriving sustenance primarily from the layer of microbes, small animals and organic material covering the leaves, rather than from the leaves themselves, while other macroinvertebrates and some fishes scrape biofilms and living algae from stones on the streambed (Bisson and Bilby 2001; Wipfli et al. 1998). Predatory macroinvertebrates and fishes prey on the animals that consume the plant material and detritus. The coarse plant and animal material is egested as fine particulate organic matter or excreted as nitrogenous compounds. Fine particulate organic matter, which is also produced in the stream by flocculation of dissolved organic matter and by physical abrasion of coarse plant material, is gathered and consumed by other types of macroinvertebrates (Bisson and Bilby 2001). The fine particulate matter is also readily decomposed by microbes to dissolved organic matter and the mineralized forms of nitrogen and phosphorus that are required for photosynthesis, thus completing the cycle.

Organic matter and nutrients in flowing water are transported downstream during the process of being recycled and are thus lost from the local stream ecosystem. Anything that retards their downstream transport, such as physical barriers and ponded water or assimilation into plant and animal tissue, increases their residence time in the local stream and helps increase the stream's productivity (Bisson and Bilby 2001; Newbold et al. 1981).

1.1.3.2 Role of Anadromous Salmonids

As indicated in the previous section, recent studies have demonstrated that anadromous fish are an important allochthonous source of organic matter and nutrients in many river and stream ecosystems. Particularly important are fish, such as Pacific salmon, that perform only one spawning migration and then die (i.e., fish with a semelparous life history) because all their organic matter remains in the stream. More than 95 percent of the body mass of Pacific salmon is accumulated from the marine environment (Groot and Margolis 1991).

After the salmon migrate upstream to their natal streams, spawn and die, their carcasses enter the stream ecosystem's heterotrophic pathways as described in the previous section. Essential nutrients and dissolved organic matter leach from the carcasses, leading to their colonization by microbes and formation of biofilms on the surrounding stream substrates (Bilby et al. 1996; Wipfli et al. 1998). The salmon also supply inorganic nitrogen to the ecosystem during their upstream migrations via excretion of ammonia and other nitrogenous compounds (Mathisen et al. 1988). And many of the eggs spawned by salmon die or are consumed and are incorporated into the heterotrophic pathways. Both direct consumption and decomposition of the salmon flesh and eggs occur. Direct consumption is generally a more important pathway for salmon flesh and eggs than it is for dead plant material. Benthic macroinvertebrates and fish, including juvenile salmon, consume the carcasses and eggs (Minakawa and Gara 1999; Naiman et al. 2002). During and shortly following the spawning season, most of the diet of trout and juvenile salmon in a stream may consist of salmon carcass flesh and eggs (Bilby et al. 1998; Eastman 2001). Decomposition of salmon carcasses and eggs and their egestion by fish and invertebrate consumers produces fine particulate organic matter, dissolved organic matter, and inorganic nitrogen, phosphorus and other nutrients. The nitrogen, phosphorus and other nutrients are thereby made available for uptake by autotrophic pathways. The autotrophic production enters the heterotrophic pathways as invertebrates and fish consume the plant material and are themselves eaten by other invertebrates and fish. Uptake and recycling of salmon derived nutrients continue well after consumption and decomposition of salmon carcasses and eggs are complete (Naiman et al. 2002).

The importance of salmon derived nutrients and organic matter to a stream's ecosystem varies greatly, but two lines of evidence have demonstrated that in many streams salmon are a significant nutrient source. Field experiments and natural experiments have documented substantially higher production of algae, benthic invertebrates and fishes in streams or stream sections that have salmon carcasses than in similar nearby streams or stream sections without salmon (Schuldt and Hershey 1995; Johnston et al. 1997; Bilby et al. 1998; Wipfli et al. 1998; Minakawa and Gara 1999; Finney et al. 2000, Minakawa et al. 2002; Naiman et al. 2002). Similarly, Richey et al. (1975) demonstrated higher production of algae and higher concentrations of nutrients in Taylor Creek, a tributary of Lake Tahoe, during a year with a high abundance of spawning kokanee salmon carcasses than during a year in which the carcasses were flushed out of the stream by high flows shortly after spawning. The second line of evidence relies on a recently developed application of stable isotope analysis. Spawning salmon, because their growth largely occurs in the sea, are enriched in heavier isotopes of nitrogen and carbon (^{15}N and ^{13}C) relative to the nitrogen and carbon derived from the stream's watershed or the atmosphere. By comparing the proportions of the heavier isotopes in the salmon tissue to those in tissues of plants and animals produced in the stream, it is possible to estimate the degree to which nitrogen and carbon in those plants and animals was derived from the salmon, which signifies the importance of the salmon in the trophic pathways. These studies have provided a great deal of direct evidence that salmon are a major source of nutrients for streams in the Pacific Northwest (Schuldt and Hershey 1995; Bilby et al. 1996; Johnston et al. 1997; Bilby et al. 1998; Cederholm et al. 1999; Finney et al. 2000; Bilby et al. 2001; Naiman et al. 2002), and have further shown that in many basins the salmon nutrients are important in the surrounding terrestrial ecosystem as well (Helfield and Naiman 2001; Naiman et al. 2002). Salmon derived nutrients are transferred to the terrestrial ecosystem as a result of feeding and defecation by bears, eagles and other terrestrial predators and scavengers (Ben-David et al. 1998; Helfield and Naiman 2002), by filtering into the water table near the stream where they are extracted by riparian plants (O'Keefe and Edwards 2002), and by being washed onto the land during flood events (Ben-David et al. 1998).

Several factors determine the importance of salmon derived nutrients and organic matter to a stream's ecosystem. Most importantly, if the stream receives few spawners, their nutrient contribution is likely to be insignificant. If salmon escapement is low because of high harvest rates or hatchery management practices, then few salmon carcasses will be available for ecosystem functions. Even if escapement and natural spawning levels are high, salmon carcasses may be washed out on the stream by high flows unless they are retained by woody debris and other barriers (Richey et al. 1975; Cederholm et al. 1989). The relative numbers of smolts emigrating from a stream and adults returning also influences the importance of salmon derived nutrients. Emigrating smolts transport nutrients from the stream ecosystem to the sea, and although their mass is much lower than that of the adults, their numbers are much greater. If the total biomass of emigrating smolts exceeds that of the spawning adults, then the salmon population will likely be a net exporter of nutrients from the stream. Sockeye salmon spawning in a lake in Idaho were estimated to contribute little to the lake's phosphorus and nitrogen budgets because relatively few survived the 1,450-kilometer migration from the ocean and the amount of nutrients exported by emigrating smolts were almost as high as the amounts imported by the adults (Gross et al. 1998). Salmon derived nutrients may also contribute little to a stream's productivity if factors other than trophic factors are limiting. For instance, poor physical habitat conditions or adverse water temperatures or water chemistry conditions may preclude high production in a stream, regardless of trophic conditions. Adding salmon carcasses to such a stream would provide little benefit to the stream ecosystem, although it could potentially enhance production of the surrounding terrestrial ecosystem, if the terrestrial system was nutrient limited.

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Oroville Reservoir, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and

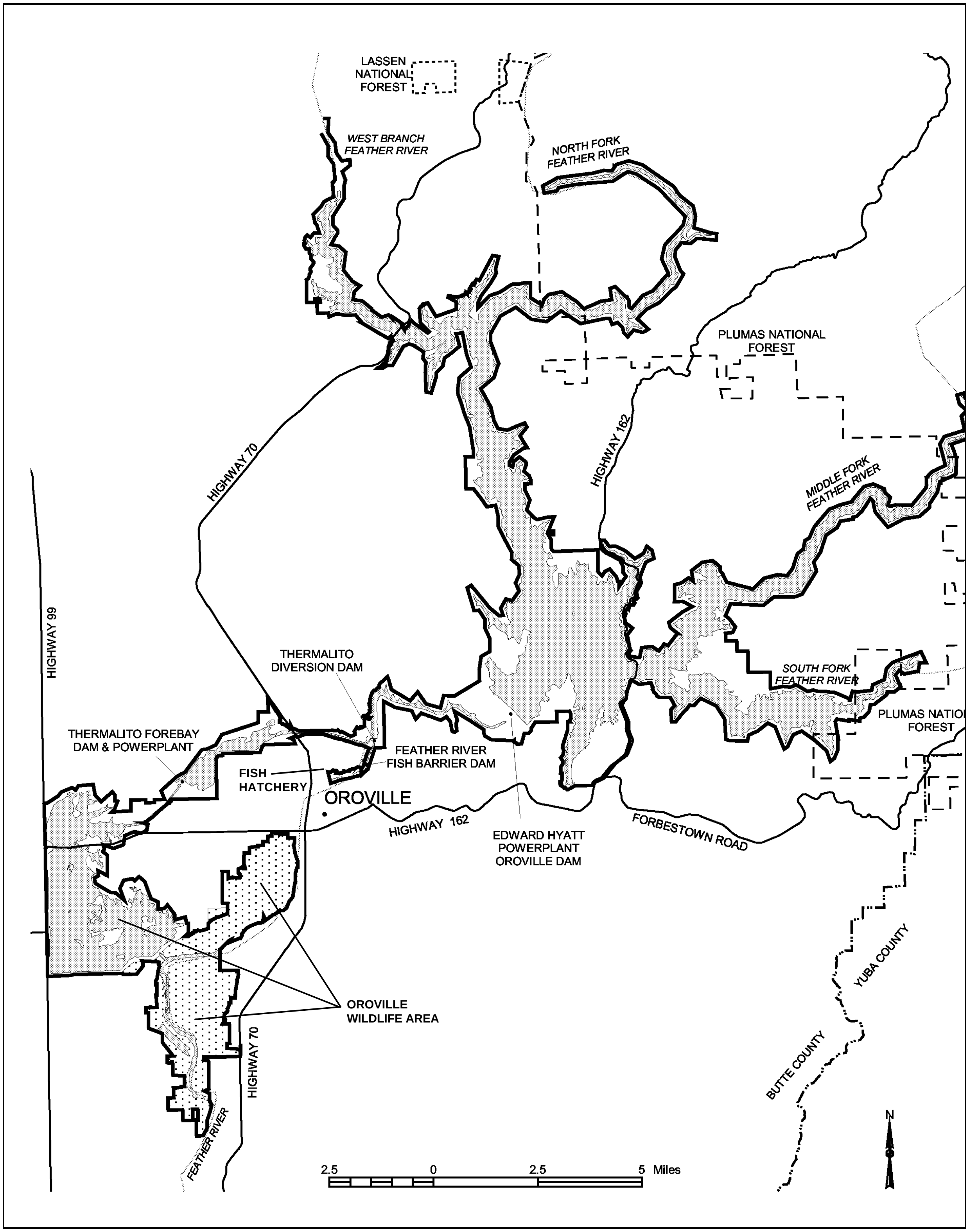


Figure 1.2-1. Oroville Facilities FERC Project Boundary

5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate 16,000 to 24,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Oroville Reservoir has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the

Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Oroville Reservoir stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Oroville Reservoir storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Oroville Reservoir. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Oroville Reservoir is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG entitled, "Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife," sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run

Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the Lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for objectives, April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Oroville Reservoir is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Oroville Reservoir to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Oroville Reservoir), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

This study is needed because project facilities currently prevent the upstream movement of anadromous fish stocks and therefore potentially affect the transfer of marine-derived nutrients and organic matter to the tributaries upstream of Oroville Reservoir. The potential influence on the nutrient transfer may contribute to a general decrease in productivity in the aquatic and terrestrial ecosystems of the upstream tributary basins. However, focused studies on the Feather River investigating the relationship between blockage of anadromous salmonid passage and nutrient and organic material levels in the upstream tributaries have never been conducted.

The potential loss of ecological productivity due to the elimination of the anadromous Chinook salmon and steelhead runs from the Feather River Basin upstream of Oroville Dam represents a continuing impact of the project on the biological resources of the area. Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the FERC Application for License for major hydropower projects, including a discussion of the fish, wildlife and botanical resources in the vicinity of the project. The discussion needs to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operation of the project. In addition to fulfilling these requirements, the specific investigations developed in this study plan will also be used in determining PM&E measures.

3.0 STUDY OBJECTIVES

The objective of this study is to collect baseline information to evaluate the effect of ongoing blockage of the upstream transfer of salmonid-derived nutrients and organic matter to the upstream tributaries. The resulting information will be used to develop and evaluate potential future PM&Es.

Individual task objectives include:

- Task 1: Document, review, and summarize available information regarding historical escapement of anadromous salmonids in the tributaries upstream of Oroville Reservoir;
- Task 2: Estimate the potential range of escapement levels of salmonids given the existing habitat of the tributaries upstream of Oroville Reservoir;
- Task 3: Estimate the range of amounts of nutrients and organic matter potentially supplied by salmonid escapement to the tributaries upstream of Oroville Reservoir;
- Task 4: Review nutrient transfer strategies to compensate for depleted anadromous salmonid populations and evaluate results of nutrient transfer programs and implementation issues.

4.0 METHODOLOGY

4.1 STUDY DESIGN

This study is designed primarily as a desktop investigation to estimate the amounts of nutrient and organic matter potentially derived from salmonid escapement in the tributaries upstream of Oroville Reservoir and to evaluate alternative nutrient mitigation and enhancement procedures, including their results and implementation issues. Estimates of amounts of nutrients and organic matter were developed by combining existing information on the nutrient and organic matter content of salmon with estimates of salmonid escapement levels in the tributaries. As noted in the introduction, two approaches were used to estimate salmonid escapement in the upstream tributaries. For the first approach, reports of historical escapement surveys were reviewed to provide estimates of the number of salmon migrating upstream prior to the construction of the Oroville Facilities. For the second approach, potential escapement estimates were developed based on the surface area of salmonid spawning habitat currently available in the upstream tributaries, and observed Chinook salmon spawning densities in the spawning habitat of several rivers, including the Feather River downstream of Oroville Reservoir. The escapement estimates derived from this second approach were used to compute the estimates of amounts of nutrients and organic matter. The escapement estimates derived from the historical escapement surveys (first approach) served principally to crosscheck the estimates derived from the tributary habitat areas and typical spawning densities (second approach). A field study component was not necessary to fulfill the study objectives, but field data obtained from Study F3.1 (habitat mapping of the tributaries upstream of Oroville Reservoir) and Study F10 (spawning densities downstream of Oroville Reservoir) were employed.

Implementation of the study was organized as follows:

- Task 1: Document, review, and summarize available information regarding historical escapement of anadromous salmonids in the tributaries upstream of Oroville Reservoir;
- Task 2: Document, review, and summarize the available literature regarding spawning densities of Chinook salmon and estimate the potential range of escapement levels of salmonids given the existing habitat of the tributaries upstream of Oroville Reservoir;
- Task 3: Document, review, and summarize the available literature regarding the nutrient and organic matter content of salmonids and estimate the potential range of amounts of nutrients and organic matter supplied by salmonid escapement given the existing habitat of the tributaries upstream of Oroville Reservoir;
- Task 4: Document, review, and summarize nutrient enhancement strategies to compensate for depleted anadromous salmonid populations and evaluate results of nutrient enhancement programs and implementation issues.

4.2 HOW AND WHERE THE STUDIES WERE CONDUCTED

4.2.1 Task 1: Historical Escapement of Anadromous Salmonids in the Tributaries Upstream of Oroville Dam

Task 1 consisted of a review and summary of the historical Chinook salmon and steelhead escapement data available for the upstream tributaries of Oroville Reservoir. In order to estimate the number of anadromous salmon whose passage to upstream tributaries and subsequent nutrient transfer was blocked by the Oroville Facilities, historical escapement data collection focused on the time period between 1944 (construction of the tributary dams) and 1968 (completion of the Oroville Facilities).

Agency reports and data relating to the escapement of salmonids from the tributaries upstream of Oroville Reservoir were collected, reviewed, and summarized. The review incorporated historical investigations by federal and state agencies, peer-reviewed literature focusing on the Feather River system, and creel census reports. In particular, the escapement estimates used to develop the initial Feather River Hatchery production goals were investigated. Interviews were conducted with several long-time or retired personnel of the CDFG and USFS and a local sport-fishing guide who provided observations and anecdotal observational information regarding the upper tributaries of the Feather River.

Reliable information on pre-project salmon and steelhead escapement in the upper Feather River and tributaries was quite limited. The terrain of Feather River canyons and tributaries was considered too rugged for standardized sampling of salmon escapement or carcass surveys (Painter 2003). At the time, resources devoted to monitoring salmon escapement in the Sacramento River basin were focused on Sacramento River mainstem locations or on other tributaries to the Sacramento River where permanent fish passage facilities aided monitoring efforts. Fish counting weirs used on the Feather River prior to completion of the Oroville Dam did not function properly, allowing fish to pass without being counted (Fry 1961). Additionally, low visibility in the Feather River caused some spawning survey estimates to be low (Fry 1961). Alternative estimates of abundance are unavailable because California Department of Fish and Game did not keep harvest data for the Feather River for the period prior to dam construction and because there is little information on tribal harvest and fishing practices across upper Feather River tributaries (McCarthy 2003).

Most of the pre-project escapement data were collected during the decade and a half prior to the completion of the Oroville Facilities in 1968. Reports providing escapement estimates from this period include DFG 1960, Fry 1961, Menchen 1966, and Painter et al. 1977.

4.2.2 Task 2: Potential Escapement Levels of Salmonids in the Tributaries Upstream of Oroville Dam Based on Spawning Habitat Availability

Task 2 evaluated the potential for salmon spawning in the upstream tributaries. Essentially, Task 2 provided escapement estimates that assumed that the Oroville Facilities did not block the passage of spawning anadromous salmonids into the upstream tributaries. The estimated escapement of Chinook salmon was calculated by combining information on available spawning habitat collected in Study F3.1 (habitat survey of the tributaries upstream of Oroville Reservoir) with information on typical fall-run Chinook salmon spawning densities from results of escapement or redd surveys in a number of rivers, mostly in California and including the Low Flow Channel downstream of Oroville Dam. Because it was not feasible to distinguish between Chinook salmon and steelhead spawning habitat in the upstream tributaries, and because no information on steelhead spawning densities was discovered, it was assumed that the estimates for potential spawning of Chinook salmon also included any potential spawning of steelhead.

4.2.2.1 Available Spawning Habitat in the Upstream Tributaries

Study F3.1 identified available Chinook spawning habitat in several upstream tributaries from the Oroville Reservoir to the first upstream migration barrier. The surveys were conducted in the South Fork, Middle Fork and the West Branch of the North Fork. GIS coverages of habitat components were developed to estimate the location, extent and relative qualities of habitat. Suitable spawning habitat locations were determined by combining the habitat component coverages to identify areas with the combinations of habitat characteristics that fit the profile of Chinook salmon spawning habitat preferences. Surface areas of spawning habitat in each tributary were computed by summing products of length and width of each of the spawning habitat reaches.

4.2.2.2 Spawning Densities

The spawning density estimates for this report were derived from a limited number of redd count surveys with spawning habitat surface area estimates from the Columbia, Tuolumne and Stanislaus Rivers (Carl Mesick Consultants 2002a and 2002b, Visser et al. 2002, Mierau 2003) and escapement and spawning habitat surface area estimates for the Low Flow Channel of the Feather River (Sommer et al. 2001, Cavallo 2003). Most existing information regarding spawning densities in streams is reported in terms of the average density of spawners in a surveyed section of stream, which is not usable for our purposes because it includes non-spawning habitat and, therefore, is biased low. If the percentage of the surveyed stream sections with spawning habitat had been reported, useful spawning density estimates could have been computed, but the reports did not provide this information. The spawning density estimate for the Feather River was for fall-run and spring-run Chinook salmon combined, while the other estimates were for fall-run only. Spawning density estimates for spring-run Chinook salmon were assumed to be within the range of estimates determined for fall-run Chinook. The redd count surveys were from the Hanford Reach of the Columbia River in Oregon (Visser et al. 2002), a 7-mile reach of the Stanislaus River downstream from Goodwin Dam (Carl Mesick Consultants 2002a, 2002b) and a 4-mile reach Tuolumne River downstream from La Grange Dam (Mierau 2003).

To convert estimates of redd density to spawning density, each redd is generally assumed to represent one spawning pair. However, redd counts may be biased low because redds are easily obscured by gravel movement, which commonly results from high flows and redd superimposition. Turbid conditions and deep-water locations also make redds difficult to see. Comparisons with escapement estimates based on carcass surveys or other methods indicated that number of redds were substantially underestimated in the redd count surveys on the Tuolumne and Columbia Rivers (Mierau 2003, Visser et al. 2002). Visser et al. (2002) concluded that their redd counts, which were made from aerial photographs, underestimated the actual number of redds by at least fifty percent. In contrast, the total number of redds counted in the Stanislaus redd surveys were similar or moderately higher than expected based on comparisons with escapement estimates (Carl Mesick Consultants 2002a, 2002b). Females may construct more than one redd, which may partially explain higher than expected redd counts (Mesick 2003). On the basis of the forgoing observations, we estimated spawning densities for the Tuolumne and Columbia Rivers by multiplying the observed redd densities by four (two fish per redd and two redds present for each redd observed), and we estimated the spawning densities for the Stanislaus River by doubling the observed redd densities.

Spawning density in the Low Flow Channel of the Feather River was estimated from the total surface area of available spawning habitat (773, 732 square feet) and the number of spawners present in the channel (Cavallo 2003). The surface area of spawning habitat was based on aerial photographic interpretation of where salmon actually constructed redds, and salmon escapement was estimated from carcass mark-recapture surveys. In addition, spawning density in Battle Creek was derived from estimates of spawning habitat area in the creek and an estimate for the surface area around each redd defended by spawning fish (Ward and Kier 1999).

4.2.2.3 Potential Escapement of Anadromous Salmonids Upstream of Oroville Dam

The potential escapement of Chinook salmon into the upper tributaries was approximated as the product of the surface area of spawning habitat available in the upstream tributaries and the range spawning densities (spawner utilization per unit of available habitat) estimated for the Columbia, Tuolumne, Stanislaus and Feather Rivers. This method of escapement calculation assumes full utilization at a range of spawning densities of the available habitat of the upstream tributaries. While the escapement numbers derived in this fashion are rough estimates, they allow for the development of a baseline reference from which to evaluate the potential significance of nutrient additions by anadromous salmonids.

The tributary reaches that were included in the habitat survey represent a small portion of the total anadromous salmonid spawning habitat made inaccessible by the Oroville Facilities. As described in Section 1.1.2, Oroville Reservoir (and the Diversion Pool) currently inundates much of the historic habitat. Furthermore, the mainstem North Fork Feather River and the smaller upstream tributaries listed in Section 1.1.2 were not surveyed, but likely contain potential spawning habitat. Therefore, estimates of total potential escapement were approximated by extrapolating the escapement estimates from the surveyed stream reaches to the unsurveyed stream reaches downstream of any migration barriers, including reaches currently inundated by Oroville Reservoir. Also included was the 5 miles of stream channel within the Diversion Pool downstream of Oroville Dam to the Fish Barrier Dam. As noted in Section 1.1.2, no information on migration barriers was obtained for several of the small tributaries, so these streams were excluded from the computations. For a few of the small tributaries, several potential migration barriers were identified: only the most upstream barrier was used for the escapement computations. Total escapement estimates were computed separately for each of the potential habitat inundation zones defined in Section 1.1.2, as follows:

$$\mathbf{E_{Zx} = E_S \times L_{Zx}/L_S}$$

Where $\mathbf{E_{Zx}}$ **= potential total escapement for stream reaches in Zone x (x = 1, 2 or 3)**
$\mathbf{E_S}$ **= computed total escapement of surveyed stream reaches**
$\mathbf{L_{Zx}}$ **= total length of stream reach channels in Zone x (x = 1, 2 or 3)**
$\mathbf{L_S}$ **= total length of surveyed stream reaches**

The estimates of escapement potential for the three inundation zones allow for straightforward comparisons between the historical escapement estimates (from Task 1) and the escapement estimates based on habitat availability (Task 2), and may also prove useful for designing potential nutrient enhancement strategies.

4.2.3 Task 3: Potential Quantities of Nutrients and Organic Matter Supplied by Anadromous Salmonids to the Tributaries Upstream of Oroville Dam

Estimates of the nutrient and organic matter content of anadromous salmonids were obtained from a review of the published literature. This review found few studies of the nutrient and organic matter content of anadromous salmonids, and most of the studies used only sockeye salmon, perhaps because of their great commercial importance. The studies generally considered only nitrogen, phosphorus and carbon content, because, as described in Section 1.1.3.1 of this report, nitrogen and phosphorus are usually the least available nutrients in the environment and carbon is the principal constituent of organic matter. Estimates of the energy (caloric) content of the fish were also found. The contribution of nutrients and organic matter by salmon was approximated from the whole body nutrient content of the unspawned fish because a salmon's body at the start of its spawning run contains all the nutrients or organic matter that it will release to the ecosystem, whether by excretion of wastes, release of gametes, or death and decay of the fish itself. This is because Pacific salmon do not consume any food during their spawning migrations.

Estimates of the nutrient, carbon and caloric content of salmon were combined with the potential escapement estimates to compute the total amount of nutrients, carbon and energy potentially supplied to the upstream tributaries and the three inundation zones by anadromous salmonids. The initial estimates of potential escapement are reported as numbers of fish, whereas the estimates of nitrogen, phosphorus, carbon and energy content are reported as percent of weight or calories per unit weight. Therefore, an estimate of average weight per fish was used to convert the escapement estimates to biomass of fish. The biomass estimates were used to convert the escapement estimates to their nutrient, carbon and caloric equivalents.

4.2.4 Task 4: Nutrient Mitigation and Enhancement Strategies and Programs

Descriptions of nutrient enrichment strategies for salmonid depleted ecosystems from other investigations, including research projects and mitigation and monitoring programs, were obtained from a wide range of sources. These sources included peer-reviewed research papers, resource agency documents, and interviews with resource agency personnel. Nearly all the research and mitigation programs are based in British Columbia, Washington State and Oregon. California has a nascent nutrient enrichment program, but attempts to contact the director of this program were unsuccessful. The descriptions of the nutrient enrichment strategies and programs were reviewed and results of both experiments and mitigations programs are summarized in the results section (Section 5.4). The different approaches and methods used for nutrient enrichment of streams were evaluated and their principal advantages and disadvantages are also summarized in the results section.

5.0 STUDY RESULTS

5.1 TASK 1: HISTORICAL ESCAPEMENT LEVELS OF SALMON AND STEELHEAD IN THE UPSTREAM TRIBUTARIES

Historical records indicate that Chinook salmon were present in all four major branches of the Feather River upstream of the present location of Oroville Dam, but their specific distribution and abundance among the smaller tributaries is largely unknown. Spring-run Chinook salmon usually spawned in higher streams and headwaters than fall-run Chinook salmon, which prefer lower regions of tributaries and mainstem river areas for spawning. Early documentation of historical salmon abundance rarely mentions steelhead distribution or abundance in the Feather River basin. Because steelhead have similar spawning habitat preferences to spring-run Chinook salmon, they are believed to have occupied the same areas as the spring-run.

Among the earliest scientific accounts of salmon in the Feather River are those by Clark (1929). Clark noted that spring-run and fall-run Chinook salmon were present in the Feather River. Clark stated that both runs were "very heavy in the Feather River previous to the building of obstructions." He further suggested that the fall-run had a cycle of 3-4 years based on statements by river residents and described the fall-run as "large, although not extremely abundant." Earlier reports stated that Indians could capture as many as 200 salmon with spears in a single night in the Feather River (Yoshiyama et al. 2001). Moyle (2002) cites historical run-size estimates of 8,000 to 20,000 spring-run Chinook salmon in the Feather River upstream of the Oroville Dam location.

Within the North Fork branch of the Feather River, spring-run Chinook salmon probably used Indian Creek, Yellow Creek, and Spanish Creek for spawning (Yoshiyama et al. 2001). In the Middle Fork, Chinook salmon probably ascended the Fall River up to Feather Falls (Yoshiyama et al. 2001). McCabe Creek and Powell Creek in the South Fork drainage were key locations of the historical fishery (Silverson 2003; McCarthy 2003).

An early report by California Department of Fish and Game (DFG) (1952) indicated that the Middle Fork of the Feather River had the "largest portion" of spring-run Chinook summer residency. This report also noted that the North Fork was a "good salmon river", the West Branch was a "fair salmon stream", and that the South Fork had limited spawning areas as a result of water diversions. Reports of salmon escapement by Fry (1961) confirmed these assessments. Fry noted that most of the spring-run used the Middle Fork for spawning, although a few adults also used the North Fork, South Fork, and West Branch of the Feather River. Fry also reported that 10,000 to 86,000 fall-run Chinook salmon spawned in the Feather River during 1953 to 1959. These estimates include reaches upstream and downstream of the location of Oroville Dam. Approximately 1,000 to 4,000 spring-run spawned in the Feather River during the same time period. Menchen (1966) reported that an average of 1,700 spring-run spawned in the Feather River from 1953 to 1962, with annual spawning estimates ranging from 0 to 4,000 fish. The entire spring-run was believed to spawn upstream of the present site of Oroville Dam. All of these estimates were considered to be minimal estimates of escapement (Fry 1961).

Another report by DFG (1960) during the pre-project time period estimated that of the anadromous salmonids spawning upstream of the present dam site, spring-run Chinook salmon had the largest run size. DFG estimated that 5,200 spring-run Chinook salmon, 2,300 fall-run Chinook salmon, and 2,000 steelhead were present upstream of the dam site. The report does not provide estimates of the distribution or abundance of these fish among the four branches of the Feather River.

Spring-run Chinook salmon and steelhead trout were present in the Feather River immediately prior to the completion of Oroville Dam in 1967, but the Oroville Project cut off their historical spawning habitat in the upper tributaries (DFG 1993; Yoshiyama et al. 2001). Run sizes of the spring-run and steelhead populations were counted by the DFG from 1963 to 1966 at a counting facility near the town of Oroville. During four years of counting preceding dam construction, an average of 1,362 spring-run and 582 steelhead returned per year (ranges: 296 to 3,362 spring-run and 416 to 914 steelhead) (Painter et al. 1977). Sommer et al. (2001) cite pre-project estimates of 1,718 spring-run Chinook salmon and 41,100 fall-run spawned in the Feather River and California Department of Water Resources (2000) cites pre-project estimates of 500 to 4,000 Feather River spring-run with an average of 2,200 per year.

5.2 TASK 2: POTENTIAL SPAWNING DENSITIES, SPAWNING HABITAT, AND ESCAPEMENT IN THE UPSTREAM TRIBUTARIES

5.2.1 Spawning Densities

Table 5.2-1 lists the different estimates for fall-run Chinook salmon redd density and spawning density obtained from studies in the lower Feather, Stanislaus, Tuolumne and Columbia Rivers and Battle Creek. The table footnotes provide notes on the methods and assumptions used to compute the estimates.

Table 5.2-1. Summary of Spawning Density Estimates for Fall-Run Chinook Salmon.

River	Year	Range of Observed Redd Densities (redds/ ha)	Mean Observed Redd Density (redds/ha)	Estimated Spawning Density (salmon/ha)	Reference
Feather	2001	---	---	8,440[1]	Cavallo (2003)
Feather	1995	---	---	6,137[1]	Sommer et al. (2001)
Stanislaus	1999	709 – 5,606[2]	2,462	4,924[3]	Carl Mesick Consultants (2002a)
Stanislaus	2000	1,063 - 6,126[2]	3,347	6,694[3]	Carl Mesick Consultants (2002b)
Tuolumne	1988	78 - 374[4]	214	856[5]	Mierau (2003)
Battle Creek	1989	---	554[6]	1,108[3]	Ward and Kier (1999)
Columbia (Oregon)	1994	56 – 84	73	292[5]	Visser et al. (2002)
Columbia (Oregon)	1995	32 – 84	54	216[5]	Visser et al. (2002)

[1] *Estimate based on escapement estimate and aerial photo estimate of spawning habitat area in Low Flow Channel.*

[2] *Estimates based on redd counts and surface area measurements in selected spawning riffles in 7 miles below Goodwin Dam.*

[3] *Estimate computed from mean redd density and assumption of two salmon per observed redd.*

[4] *Estimates based on redd counts and surface area measurements in selected spawning riffles in 3 to 4 miles downstream of La Grange Dam.*

[5] *Estimate computed from mean redd density and assumption of four salmon per observed redd.*

[6] *Estimate computed from measured spawning habitat area and assumption of 194 square feet per redd (includes redd plus defended territory).*

The estimated salmonid spawning densities (Table 5.2-1) are highly variable due to differences in spawning habitat quality and hydrological characteristics of the river, and the number of hatchery produced fish in the river. As noted in Section 4.2.2, the spawning density estimates are also affected by differences in survey methodology and assumptions and sampling conditions (i.e., redd counts biased by turbidity or by degree of superimposition of redds).

5.2.2 Available Spawning Habitat in the Upstream Tributaries

Salmonid spawning habitat, which was identified as riffle habitat with suitable gravel substrate, was found in all three tributaries surveyed. Table 5.2-2 lists the total surface area of spawning habitat found in the surveyed reach of each tributary. The tributary with the greatest surface area of suitable spawning habitat was the South Fork.

Table 5.2-2. Surface Area of Salmonid Spawning Habitat in the Feather River Tributaries Upstream of Oroville Reservoir.

Tributary	Upstream and Downstream Limits of Surveyed Reaches	Total Surface Area of Spawning Habitat (hectares)
West Branch of North Fork	Miocene Dam to 121° 33’ 27.01” W and 39° 42’ 35.81” N (three separate sections surveyed)	0.2014
Middle Fork Feather River	Curtain Falls to 121° 17’ 54.46” W and 39° 36’ 45.72” N	0.3598
South Fork Feather River	Ponderosa Dam to 121° 19’ 25.33” W and 39° 32’ 31.98” N	0.7052
Total for three tributaries	NA	1.2664

5.2.3 Potential Escapement of Anadromous Salmonids Upstream of Oroville Dam

This section develops estimates of the potential escapement of salmon and steelhead upstream of Oroville Dam and the Fish Barrier Dam assuming absence of the Oroville Facilities. A scenario with the Oroville Project absent includes upstream migration and spawning of adult salmon and steelhead as far as the first impassable non-project barrier, natural production of the Feather River salmonids (i.e., no Feather River Hatchery), and no inundation of the Feather River channel upstream of the Fish Barrier Dam (i.e., no Oroville Reservoir nor Diversion Pool). As described in Section 4.2.2, the escapement estimates for the surveyed reaches of the tributaries upstream of Oroville Reservoir were computed as the product of the surface area of spawning habitat that currently exists in those reaches (Table 5.2-2) and the estimates of spawning density (Table 5.2-1). The escapement estimates for the surveyed reaches were then used to develop approximate estimates of potential spawning escapement for the portions of the Feather River and its tributaries in each of the reservoir inundation zones. For the purpose of these computations, the North Fork of the Feather River is considered to be an extension of the mainstem channel extending downstream to the Fish Barrier Dam.

Table 5.2-3 gives the lengths of the sections of the tributaries included in the habitat surveys and the escapement estimates for these stream sections. The table gives a range of escapement estimates for each tributary. These ranges were computed from the range of spawning density estimates in Table 5.2-1 (216 to 8,440 spawners per hectare) and the estimates of spawning habitat surface area in Table 5.2-2. The upper estimate in the range of spawning densities is for the Feather River in the Low Flow Channel, which as previously noted, is believed to be unnaturally high because of the many hatchery return fish. However, this estimate is not much higher than the year 2000 estimate for the Stanislaus River. Table 5.2-3 also provides total lengths of the stream channels in each of the inundations zones and the approximated total escapement estimate for each zone.

Table 5.2-3. Estimates of Channel Length and Potential Escapement for the Surveyed Sections of the Upstream Tributaries and Sections within each of the Inundation Zones.

Surveyed Stream Section or Inundation Zone	Channel Length (miles)	Estimated Escapement (number of fish)
West Branch of North Fork Feather River	2.55	44 – 1,700
Middle Fork Feather River	0.68	78 – 3,037
South Fork Feather River	1.69	152 – 5,952
Total for the surveyed reaches	4.92	274 – 10,689
Zone 1 (never inundated)	8.39	467 – 18,228
Zone 2 (fluctuation zone)	23.90	1,331 – 51,924
Zone 3 (permanently inundated)	40.71	2,267 – 88,445
Total for three inundation zones	73.00	4,065 – 158,597

The escapement estimates in Table 5.2-3 are generally higher than the estimates of historical escapement presented in Section 5.1. Historical escapement in Zones 1 and 2 likely consisted entirely of spring-run Chinook salmon and steelhead, whereas for Zone 3, which includes the channel downstream of Oroville Dam to the Fish Barrier Dam, the historical escapement probably also included many fall-run Chinook salmon. Historical escapement estimates for spring-run Chinook salmon and steelhead, all of which are assumed to have spawned upstream of the Oroville Dam location, range from

582 steelhead and 1,362 spring-run (Painter 1977) to 2,000 steelhead and 5,200 spring-run (DFG (1960). The totals for steelhead plus spring-run (1,944 to 7,200) are much closer to the lower limit of the range for Zones 1 plus 2 in Table 5.2-3 (1,798) than to the upper limit of the range (70,152). The historical escapement estimates for fall-run Chinook salmon range from 41,000 (Sommer et al. 2001) to 86,000 (Fry 1961), but the majority of these fish spawned downstream of the Fish Barrier Dam location, so comparisons with the estimates in Table 5.2-3 are difficult to interpret.

5.3 TASK 3: NITROGEN, PHOSPHORUS, CARBON AND ENERGY POTENTIALLY SUPPLIED BY ANADROMOUS SALMONIDS TO THE UPSTREAM TRIBUTARIES

Table 5.3-1 provides estimates from five different published studies of the nitrogen, phosphorus and carbon content of sockeye salmon. The table also gives estimates of nitrogen and phosphorus content of pink salmon and the energy (caloric) content of sockeye salmon in particular and Pacific salmon in general. Note that Mathisen et al. (1988) report nitrogen, phosphorus and carbon content and calories for both unspawned and spawned out sockeye salmon. The information on spawned out salmon was not used in the analyses for this report and is included only to illustrate the impact of spawning on the body contents. The estimates of the other studies are for unspawned salmon only. Except for the estimates for spawned out salmon, most of the estimates from the different studies are reasonably similar. No studies reporting nutrient and organic matter content of Chinook salmon or steelhead were found, so the results for sockeye and pink salmon were used for this study.

Table 5.3-1. Estimates of the Nutrient and Energy Content of Pacific Salmon.

Species / Condition	Nitrogen (percent of fresh weight)	Phos-phorus (percent of fresh weight)	Carbon (percent of fresh weight)	Energy (kilocalories per pound of fresh weight)	Source
Sockeye (unspawned)	2.6	0.5	14.0	680.4	Mathisen et al. (1988)
Sockeye (spawned out)	2.3	0.4	7.3	362.9	Mathisen et al. (1988)
Sockeye	3.0	0.4	---	---	Schuldt and Hershey (1995)
Sockeye	3.0	0.4	---	---	Larkin and Slaney (1997)
Sockeye	---	0.34	---	---	Koenigs and Burkett (1987)
Pink	2.6	0.35	---	---	Gende (2001)
Salmon (unspecified)	3.0	0.325	---	---	Stansby and Hall (1965) (in Ashley and Slaney 1997)
Pacific salmon (all)	---	---	---	725.7	Brett (1995)

As noted in Section 4.2.3, the estimates of potential escapement upstream of Oroville Dam are reported as numbers of fish, whereas the estimates of nitrogen, phosphorus, carbon and energy content are reported as percent of weight or calories per unit weight. The average weight of spring-run Chinook salmon adults returning to the Feather River hatchery during 2002 and 2003 was used to convert the escapement estimates to their biomass equivalents (Table 5.3-2). This weight was about 30 pounds (Kastner 2003). The potential annual additions (loadings) from salmon to the upstream tributaries of nitrogen, phosphorus, organic carbon and energy were computed as the products of the biomasses escapement estimates and percentages or calories in Table 5.3-1. Table 5.3-2 gives the estimated potential annual loadings for each of the tributary sections that was surveyed for habitat and for each of the three inundation zones. The table gives ranges of estimates for the annual loadings. The minimums of the ranges are computed as the product of the escapement biomass minimums and the minimum estimates for unspawned fish of nitrogen, phosphorus, carbon and caloric content (Table 5.3-1), whereas the maximums of the ranges are computed from the maximum biomass and nutrient and energy contents.

Table 5.3-2. Estimates of Total Annual Loadings of Nitrogen, Phosphorus, Organic Carbon and Energy to the Surveyed Sections of the Upstream Tributaries and Sections within each of the Inundation Zones from Potential Escapement of Anadromous Salmonids.

Surveyed Stream Section or Inundation Zone	Escapement Biomass (pounds)	Nitrogen (pounds)	Phos-phorus (pounds)	Organic Carbon (pounds)	Energy (millions of kilocalories)
West Branch of North Fork Feather River	1,320 – 51,000	34 – 1,530	4.3 - 255	185 – 7,140	0.9 – 37
Middle Fork Feather River	2,340 – 91,110	61 – 2,733	7.6 - 456	328 – 12,755	1.6 – 66
South Fork Feather River	4,560 – 178,560	119 – 5,357	15 - 893	638 – 24,998	3.1 – 130
Total for the surveyed reaches	8,220 – 320,670	214 – 9,620	27 – 1,603	1,151 – 44,894	5.6 - 233
Zone 1 (never inundated)	14,010 – 546,840	364 – 16,405	46 – 2,734	1,961 – 76,558	9.5 - 397
Zone 2 (fluctuation zone)	39,930 – 1,557,720	1,038 – 46,732	130 – 7,789	5,590– 18,081	27 – 1,130
Zone 3 (permanently inundated)	68,010 – 2,653,350	1,768 – 79,600	221–13,267	9,521–374,469	46 – 1,926
Total for three inundation zones	121,950–4,757,910	3,171– 42,737	396–23,790	17,073–666,107	83 – 3,453

The nitrogen, phosphorus and organic carbon estimates in Table 5.3-2 represent potential total annual loadings to the streams, assuming the salmon and steelhead carcasses, dead eggs and waste material are completely decomposed within a year of the salmon's death. Spring-run salmon, which was likely the most abundant anadromous salmonid that spawned in the streams that are now tributaries to Oroville Reservoir, spawn during late summer and early fall, when water temperatures are near their annual maximums and decomposition rates, therefore, would be high. Even in cold water, salmon carcasses are mostly decomposed after two to three months (Richey et al. 1975; Cederholm et al. 1989). Parmenter and Lamarra (1991), using rainbow trout carcasses (about 0.2 to 0.3 pounds wet weight) in a cold-water marsh, measured loss rates of dry weight and of specific elements, including nitrogen and phosphorus. The fish lost over 60 percent of their weight, 90 percent of their nitrogen content and 50 percent of their phosphorus content after only a month in water about 65 degrees Fahrenheit. The loss rates slowed greatly in subsequent months, with about 20 percent of weight, 5 percent of nitrogen and 40 percent of phosphorus remaining after three months. The remaining phosphorus was mostly within bones, which are much slower to decompose than the rest of the carcass. Johnston (2001) determined loss rates for nitrogen, phosphorus and carbon from sockeye salmon carcasses. He found that the carcasses lost nitrogen and carbon at rates of about four percent per day, whereas the carcasses lost phosphorus at rates of about 2.5 percent per day. The results of these studies suggest that nearly all of the nitrogen, most of the organic matter, but only about 60 percent of the phosphorus within a salmon's body would be released to the ecosystem within a yearly cycle, and that most of what is released is released within two months of the death of the salmon.

To evaluate the significance of the nutrients potentially supplied by salmon and steelhead to the upstream tributaries, it is useful to compare the amounts supplied (loadings) to the amounts currently present in the streams. Existing information on the amounts currently present is expressed in terms of concentrations, so the loadings need to be similarly expressed. Approximate estimates of the expected increases in concentrations of nitrogen, phosphorus and organic carbon derived from salmon in the upstream tributaries were computed from the loading rates in Table 5.3-2 and information on streamflows during months that salmon carcasses would be decomposing. There are no flow data for the individual tributaries, but total inflow to the Oroville Reservoir averaged 2,583 cfs during August through November (1995 – 2002 water years), when most of the spring-run salmon spawning and decomposition of carcasses would occur. The total volume of water flowing over the salmon carcasses in four months of 2,583 cfs flow would be about 7.75×10^{11} liters.

To compute the concentrations of nitrogen, phosphorus and carbon released from the salmon carcasses, it was assumed that salmon carcasses would be added to the streams at a fairly constant rate over an August through October spawning season, and that most of the nitrogen and carbon and about fifty percent of the phosphorus contained in a carcass is released within a month of the death of the fish. Based on these assumptions the expected increases in concentrations of nitrogen and organic carbon were calculated by dividing the total loadings of these elements in the three inundation zones (Table 5.3-2) by the total volume of water (7.75×10^{11} liters) in which these nutrients were diluted during four months of carcass decomposition. The expected increase in phosphorus concentration was computed by dividing 50 percent of the total phosphorus load by the total water volume. The ranges of the loadings were used to compute ranges of concentration increases.

The use of total reservoir inflow rather than separate tributary discharges to estimate the dilution flow precludes estimation of nutrient concentrations for individual tributaries. Therefore, the nutrient concentrations for the three inundation zones were estimated using the inundation zone loading estimates. However, even for the inundation zone estimates of nutrient concentrations the use of total inflow creates problems. This is particularly true for the Zone 1 estimates. Many of the tributaries that contribute significant flow have no stream channel in Zone 1 and, therefore, contribute nothing to the estimated nutrient load. For instance, the North Fork and South Fork, which provide substantial amounts of inflow, have no Zone 1 stream channels (see Figure 1.1-1) and, therefore, add nothing to the nutrient loading estimates. As a result, total inflow overestimates the dilution flow in Zone 1 and the nutrient concentrations are underestimated. This error has less effect on the Zone 2 estimates and probably has little effect on the Zone 3 estimates.

The computed ranges of concentrations for the three inundations zones are presented in Table 5.3-3. Note that our computations assume that nutrient concentrations in the three Zones are independent. In fact, however, the increases in nutrient concentrations are to some degree cumulative as the nutrients are transported downstream from Zone 1 through Zone 3. Because some nutrients are reabsorbed by autotrophs as they move downstream, the degree to which they cumulate downstream is unknown. The total for the three zones, of course, is cumulative.

Table 5.3-3. Estimates of Average Increases in Concentrations of Total Nitrogen, Phosphorus and Organic Carbon during August through November Resulting from Escapement of Anadromous Salmonids in Upstream Tributaries.

Inundation Zone	Escapement Biomass (pounds)	Nitrogen (µg/L)	Phosphorus (µg/L)	Organic Carbon (µg/L)
Zone 1 (never inundated)	14,010 – 546,840	0.21 – 9.65	0.01 – 0.80	1.15 – 45.04
Zone 2 (fluctuation zone)	39,930 – 1,557,720	0.61 – 27.49	0.04 – 2.29	3.29 – 128.31
Zone 3 (permanently inundated)	68,010 – 2,653,350	1.04 – 46.82	0.07 – 3.90	5.60 – 218.55
Total for three inundation zones	121,950–4,757,910	1.87 – 83.98	0.12 – 7.00	10.04 – 391.90

An effort was made to estimate the ambient concentrations of nitrogen, phosphorus and organic carbon in the upstream tributaries from sampling conducted during the past decade at a variety of tributary locations within about 10 miles from the reservoir. The reporting limits for concentrations from these samples have ranged from 10 to 100 µg/L for total dissolved inorganic nitrogen and 10 to 50 µg/L for total phosphorus, and the reporting limit for dissolved organic carbon was 100 µg/L (DWR unpublished data). These reporting limits greatly exceed the lower limits of the ranges of potential concentration increases attributable to salmon, and also exceed the upper limits for phosphorus and, in Zone 1, for nitrogen and carbon (Table 5.3-3). About 70 percent of the results from the upstream tributary water samples were below the reporting limits, so meaningful comparisons with the potential increases due to anadromous salmonids are not feasible. These reporting limits are suitable for detecting potential water quality problems associated with high levels of nutrients, such as eutrophication, ammonia and nitrite toxicity or high nitrates and nitrites in drinking water, but they are too high for evaluating the potential for nutrient limitation in the streams.

5.4 TASK 4: NUTRIENT MITIGATION AND ENHANCEMENT STRATEGIES AND PROGRAMS

Fisheries resource agencies in the Pacific Northwest have long recognized the importance of nutrient additions derived from sockeye salmon spawning runs to their nursery lakes, and have instituted successful lake fertilization programs to mitigate for human-induced reductions in the size of the spawning runs (Mathisen et al. 1988; Johnston et al. 1990; Stockner and Macisaac 1996; Larkin and Slaney 1997; Schmidt et al. 1998; Cederholm et al. 1999; Finney et al. 2000; Rosenau 2001; Thompson 2001; Naiman et al. 2002). Mitigation and enhancement programs to increase nutrients and organic matter in streams that have experienced losses or reductions in salmon are more recent. Fisheries managers have pursued a variety of approaches to increase nutrients and/or organic matter, including the direct application of inorganic nitrogen and phosphorus fertilizers (Johnston et al. 1990; Ashley and Slaney 1997; Ashley 2001; McCusker 2001; Wilson 2001; Ashley and Stockner 2003; Michael 2003a; Sterling and Ashley 2003); deposition of salmon and steelhead carcasses obtained from fish hatcheries (Ashley and Slaney 1997; Bilby et al. 1998; Ashley and Stockner 2003; Michael 2003); broadcasting of carcasses "analogs", which are fish carcasses and other fish waste that have been dried, sterilized and compressed (Michael 2003a); and increasing escapement goals for naturally spawning salmonids (Schmidt et al. 1998; Bilby et al. 2001). Fisheries managers consistently stress that the implementation of all nutrient enrichment strategies to mitigate for depleted salmon stocks, other than increasing escapement of naturally spawning salmonids, should be considered temporary measures to help fully restore the natural spawning populations (Ashley and Slaney 1997; Ashley and Stockner 2003; Lackey 2003).

5.4.1 Results of Nutrient Enhancement Experiments

This section summarizes the results of nutrient enhancement experiments and field studies using either inorganic fertilizers or salmonid carcasses. The experiments test

the effect of nutrient enhancements on individual growth and population responses of algae, macroinvertebrates and fish in the streams.
Application of inorganic fertilizers in streams has been shown to cause substantial increases in fish growth, survival, and condition factors (Michael 2003b). The earliest, most intensive and most long-lasting experimental program to evaluate effects of artificial fertilizer applications in streams has been on the Keogh River and several other rivers in British Columbia (Johnston et al. 1990; Ashley and Slaney 1997; Slaney et al. 2003; Ward et al. 2003; Wilson et al. 2003). The experimental designs employed include: 1) adding liquid fertilizer to some river sections and comparing growth and other biotic responses of periphyton, macroinvertebrates and salmonids in these sections to their biotic responses in control sections with no fertilizer treatment, 2) adding fertilizer in certain years and comparing biotic responses of the organisms to their biotic responses in control years when no fertilizer was added, and 3) adding fertilizer to rivers and comparing biotic responses of the organisms to their biotic responses in similar, control rivers with no fertilizer additions. In all cases, the results of the experiments showed increased growth, survival, biomass and/or production at all trophic levels. In the Keogh River, fertilization resulted in striking increases in the weights of steelhead and coho salmon fry. Salmonid biomass was about twice as high in fertilized treatment reaches as in control reaches. Production of steelhead was 62 percent higher in years of fertilizer addition than in the pre-treatment years. And steelhead in treatment years smolted about a year earlier than those in pre-treatment years. In other rivers, periphyton chlorophyll *a*, biomass of benthic macroinvertebrates, and mean weight and biomass of steelhead, resident rainbow trout and mountain whitefish increased several fold in fertilized reaches as compared to control sections (Ashley and Slaney 1997). Affects of fertilization in these streams were detected at least 15 kilometers downstream from the location of fertilizer additions.

Applications of salmon carcasses in streams have also resulted in substantial increases in several indices of productivity. Field experiments and natural experiments have documented substantially higher production of algae, benthic invertebrates and fishes in streams or stream sections that have salmon carcasses than in similar nearby streams or stream sections without carcasses (Schuldt and Hershey 1995; Johnston et al. 1997; Bilby et al. 1998; Wipfli et al. 1998; Minakawa and Gara 1999; Finney et al. 2000, Minakawa et al. 2002; Naiman et al. 2002). Similarly, Richey et al. (1975) demonstrated higher production of algae and higher concentrations of nutrients in Taylor Creek, a tributary of Lake Tahoe, during a year with a high abundance of spawning kokanee salmon carcasses than during a year in which the carcasses were flushed out of the stream by high flows shortly after spawning.

Use of carcass analogs to enhance stream nutrients has not been tested, but results should be essentially the same as for use of carcasses. The main difference between carcasses and carcass analogs would likely be a more rapid decomposition of the carcass analogs.

5.4.2 A Review of Nutrient Enhancement Methodologies

This section discusses the different methodologies, grouped as inorganic fertilizer application or use of fish carcasses, that have been used, both in experiments and in established mitigation programs, to enhance nutrients in streams that have depleted runs of anadromous salmonids, and summarizes their advantages and disadvantages (Table 5.4-1). The section also briefly reviews the nutrient enhancement programs of Oregon and Washington State, which have active nutrient enhancement programs for many of their streams. Finally, this section provides a comparison of the Oroville Basin upstream tributary salmon escapement estimates (Section 5.2) and the increased nutrient concentrations (Section 5.3) based on these escapement estimates with target levels for nutrient concentration and fish carcass density established by the Washington State Department of Fish and Wildlife.

It should be noted that any nutrient enhancement program must be carefully planned and monitored to avoid adding excessive levels of nutrients to streams. Excessive nutrients result in eutrophication, which has many undesirable consequences. It is difficult to generalize about nutrient levels that result in eutrophication, but soluble reactive phosphorous concentrations greater than 10 µg/L have been found to stimulate excessive production of algae in streams and rivers (Ashley and Stockner 2003). Dissolved inorganic nitrogen concentrations of 100 ug/L or less may stimulate algal blooms in lakes (Boyd 2000). As noted in Section 5.3, excessive levels of ammonia, nitrite or nitrate result in toxicity and violations of drinking water standards.

5.4.2.1 Inorganic Fertilizers

Inorganic fertilizers can be added to a stream in either liquid or granular form or through slow-release pellets. The expense of fertilizers and cost of maintaining the automated systems used to supply a constant level of nutrients to the treatment areas, have been the primary drawback to the use of these fertilizers. The slow-release pellets are a recent improvement because they release nutrients very slowly and therefore do not require automated application systems. Another complication with the use of inorganic fertilizers is public acceptance, because of a long history of unintentional additions of nitrogen and phosphorus that have produced undesirable eutrophication of streams and lakes. However, the salmon streams selected for nutrient enhancement are oligotrophic and the amounts of nutrients added are well below levels that would cause undesirable effects. The added nutrients are usually taken up rapidly in the food chain and are not detectable in the water column outside the treatment area (Michael 2003b).

The amount of fertilizer added to a stream is selected to achieve predetermined target levels of nutrient concentrations (Ashely and Slaney 1997). The target levels for streams in the Pacific Northwest are generally based on the responses of periphyton and other organisms in the field experiments discussed in the previous section. Target levels for dissolved inorganic nitrogen concentrations have ranged from 15 to 50 µg/L

Table 5.4-1. Nutrient Enhancement Measures: Potential Advantages and Disadvantages.

Nutrient Source	Application Technique	Potential Advantages	Potential Disadvantages
Salmonid carcasses (hatchery)	Manual or aerial (helicopter)	Readily available in season Low cost of carcasses No maintenance Optimal nutrient content Release nutrients gradually Relatively immobile in stream Rapid transfer to all trophic levels Annual application Attracts public interest Established method	Heavy, very costly to transport Seasonal availability Fish disease issues Water quality issues Aesthetics issues Marine-derived contaminants
Fish carcass "analogs" (dried, sterilized and compressed fish material)	Manual or aerial (helicopter)	Light, inexpensive to transport No diseases No maintenance Annual application Optimal nutrient content Rapid transfer to all trophic levels	Costly to produce Readily transported by flows Untested method
Slow-release solid fertilizer ("briquettes")	Manual or aerial (helicopter	Light, inexpensive to transport No maintenance No diseases Release nutrients gradually Annual application Control N to P ratio Established method	High cost of fertilizer Slow transfer to upper trophic levels May lack some beneficial nutrients Contaminants from phosphate ore Permitting issues
Liquid or granular fertilizers	Manual drip stations, flow-proportional injection and pre-programmed systems for liquids fertilizers. Automatic application stations for granular fertilizers	Low cost of fertilizer Light, inexpensive to transport No diseases Can vary nutrient delivery rate with flow Control N to P ratio Established method	High initial cost of application systems Routine maintenance required Slow transfer to upper trophic levels Prone to spiking concentrations Prone to vandalism Potential damage from flooding/bank erosion Contaminants from phosphate ore Permitting issues

and target levels for soluble reactive phosphorus concentration have ranged from 3 to 15 µg/l (Johnston et al. 1990; Slaney 2001; Wilson 2001; Michael 2003b). However, soluble reactive phosphorus concentrations above 10 µg/L were found to produce excessive algal growth (Ashley and Stockner 2003). Because phosphorus is generally the limiting nutrient in streams of the Pacific Northwest, fertilizer additions are usually designed to meet the phosphorus target concentrations. However, use of a fertilizer with an appropriate nitrogen to phosphorus ratio helps achieve targets for both nutrients. The daily amount of nutrient required to achieve the target nutrient concentration level is computed as follows (modified from Ashley and Slaney 1997):

N = Q (cfs) x 28.316 (liters per cubic foot) x 86,400 (seconds per day) x (T - A) x 2.204623x10^{-9} (pounds per microgram)

Where N = pounds of nutrient
Q = discharge of stream (cfs)
T = target concentration (µg/L) of nutrient in the stream
A = ambient concentration (µg/L) of the nutrient in the stream

The pounds of fertilizer needed are computed from the pounds of nutrient as the reciprocal of the proportion, by weight, of the nutrient in the fertilizer.

It should be noted that application of inorganic fertilizers would not improve a stream's productivity if nitrogen and phosphorus were not limiting. In heavily shaded streams, for instance, low light levels may limit growth of autotrophs more than the availability of nutrients.

5.4.2.2 Fish Carcasses

Distributing fish carcasses has been the most widely used method for nutrient supplementation in the Pacific Northwest. The primary advantages of this method are low cost, an optimal combination of nutrients for fish, and the immediate availability of the nutrients and organic matter to fish and other higher trophic level organisms (Table 5.4-1). The cost of carcasses is low because surplus hatchery returns or hatchery mortalities are readily available. Carcasses provide an optimal combination of nutrients for fish, including micronutrients whose importance in a stream may not be recognized, because they closely match the nutrient content of the fish. The nutrients in carcasses are rapidly available to fish and other organisms because the carcasses provide organic matter and are therefore directly consumed by the fish and other scavengers. In contrast, nutrients supplied as inorganic fertilizers are available to salmonids only after they work their way up the food chain from autotrophs, such as algae, and herbivorous invertebrates and fish. In some situations, such as deeply shaded or heavily scoured streams, autotrophic production may be low regardless of nutrient levels, so direct availability of nutrient to higher trophic levels may be essential (Bilby et al. 1996). A secondary advantage of using salmon carcasses is that distributing the carcasses has proven successful in increasing the visibility of resource agency habitat enhancement efforts and has attracted community involvement in habitat restoration.

Disadvantages of using fish carcasses to enhance nutrients are that they must be checked for pathogens prior to release, storage requires freezing until their target disposition date, and the cost of transporting and broadly distributing the carcasses is high. An additional potential disadvantage that has not been sufficiently examined is that salmon carcasses generally contain elevated levels of toxic contaminants. Salmon bioaccumulate pesticides and heavy metals that have washed into the ocean and they transport these contaminants upstream during their spawning runs. Transport of contaminants by anadromous salmon has resulted in elevated contaminant levels in pristine ecosystems where they spawn (Naiman et al. 2002).

Bilby et al. (2001) recently developed an ecologically sound procedure for establishing target levels for placement of salmon carcasses in streams. Using the isotope analysis methods described in Section 1.1.3.2, these investigators measured levels of marine-derived nitrogen in juvenile coho salmon from a number of streams and examined how these levels were related to the abundance of coho salmon spawning in the streams in the previous spawning season. They found that in streams with relatively low densities of spawning salmon, the levels of marine-derived nitrogen in the young salmon increased rapidly with increased abundance of spawners. However, as density of spawners increased, the increases in marine-derived nitrogen moderated and no increases were observed at salmon densities above about 0.15 kilograms per square meter. The investigators considered that these results most likely indicated that increases in salmon carcasses provided increased food resources for juvenile salmon up to the saturation level of 0.15 kilograms per meter squared, but that above the saturation level food resources were not limiting. As discussed below, the 0.15 kilograms per meter estimate has been used by Washington State resource agencies to develop target levels for placement of salmon carcasses in stream for different anadromous salmonid species.

The use of carcass analogs is a relatively new technology and is currently in development and testing (Michael 2003a). The advantage of analogs is twofold. First, they are lighter in weight per unit of nutrient (when compared to carcasses). Second, analogs present a much lower risk of pathogen transfer because they are treated for pathogens during processing.

5.4.2.3 Oregon and Washington Nutrient Enhancement Programs

<u>Oregon</u>

Resource managers in Oregon recently have recognized the importance of salmon carcasses as a source of marine-derived nutrients for food webs in stream environments. The Oregon Department of Fish and Wildlife currently has a Memorandum of Agreement (MOA) with the Oregon Department of Environmental

Quality for their fish carcass placement and stream enrichment programs. Chinook salmon, coho salmon, and steelhead are the only species used for stream enrichment in Oregon. A maximum density of 2,500 pounds per mile of salmon and/or steelhead carcasses is specified in the MOA for these programs. Carcasses are placed in streams only when or where they will not adversely impact water quality or spread pathogens. Streams in each basin are chosen to meet all conditions described in the MOA and in NPDES permits. Carcasses are distributed within a basin at locations historically or currently used by anadromous salmonids for spawning. In 2002 - 2003, carcasses are planned for nutrient enrichment purposes in 58 river basins across Oregon.

Washington

Since the early 1990s, salmon carcasses have been used to supplement stream production in Washington. Resource managers are required to submit an application to the Washington Department of Fish and Wildlife (WDFW) and the Washing Department of Ecology for environmental review of any proposed nutrient restoration project. An NPDES permit also must be obtained before a nutrient restoration project is implemented. Approval for nutrient restoration projects traditionally is granted on a case-by-case basis.

Four options are currently being considered to increase nutrient levels in freshwater ecosystems and boost ecosystem productivity in Washington rivers and streams. These options include 1) application of fertilizers, 2) application of carcass analogs ("fish cakes"), 3) disposition of surplus carcasses from fish hatcheries, and 4) allowance of increased levels of natural spawning by natural fish in target tributaries (Michael 2003b). Research on these four options is ongoing and standard protocols and statewide guidelines for these nutrient enrichment projects are being drafted (Michael 2003c).

Target levels for inorganic fertilizer enrichment are to achieve an instantaneous soluble reactive phosphorus level over a 120-day treatment period of 3 to 5 µg/L. As previously noted, these target levels are based on a series of fertilization experiments on streams in British Columbia.

Target levels for salmon carcasses and carcass analogs are based on the relationship, described previously in this section, between marine-derived nitrogen levels in juvenile salmon and densities of spawners (Bilby et al. 2001). The original target level of 0.15 kilogram per square meter (kg/m^2) was developed for coho salmon, which is a low-density spawning species. Steelhead trout have similar spawning characteristics to coho salmon and, therefore, the 0.15 kg/m^2 target is also used for steelhead streams (Michael 2003b). At the other extreme, pink, sockeye and chum salmon are mass spawning species (Michael 2003b). The target carcass density for streams with these three species is 0.78 kg/m^2, as determined from studies on uptake of marine-derived nitrogen by insects in sockeye salmon spawning streams (Michael 2003d). Chinook salmon is assigned an intermediate target density of 0.39 kg/m^2 (Michael 2003b).

Stream surface areas for all of these carcass density target levels are based on bank-full stream widths.

The target levels for carcass analogs are based on the fresh weight target densities for carcasses adjusted for the weight of water removed from the carcasses during processing to produce the analogs.

5.4.2.4 Comparing Estimated Phosphorus Levels and Carcass Densities from Potential Escapement in the Upstream Tributaries to Washington State's Nutrient Enhancement Program Target Levels

This section compares the Washington State target levels for carcass density and phosphorus concentration to our estimates of potential salmon escapement to the upstream tributaries and of the concentrations of phosphorus potentially contributed by these salmon. The target levels can be considered optimal levels for healthy ecosystem production of the Washington stream, so this comparison serves to relate the loss of nutrients from the upstream tributaries to an optimal level of phosphorus or carcasses in streams. It should be noted that the target levels are for salmon and steelhead streams in Washington State, which may have very different nutrient requirements than the streams of the Oroville Reservoir Basin. Carcass densities (escapement) and nutrient concentrations in Zone 1 are the focus of the comparisons because any PM&E measures would address only stream sections in this zone. Only Zone 1 has tributary reaches that are never inundated by the reservoir and thus always maintain stream ecosystem functions. However, estimates for Zone 2, which includes many miles of stream channel that are only occasionally inundated, are included for purposes of comparison.

The Washington State target level for Chinook salmon carcass placement is 0.39 kg/m^2 of stream, using bank-full width to estimate stream surface area. Equivalent carcass densities for the tributaries upstream of Oroville Reservoir were computed from the range of biomass escapement estimates of the surveyed stream sections (Table 5.3-2) and the total surface areas of the surveyed stream sections (including spawning and non-spawning habitat). Average carcass densities, weighted by the lengths and relative sizes of tributary channels present in Zone 1 and Zone 2, were computed from the ranges of escapement estimates for the surveyed stream sections. Note that the surface areas of the surveyed stream sections were based on less than bank-full widths and, therefore, the carcass densities are overestimated. The weighted average carcass densities for Zone 1 ranged from 0.03 to 1.18 kg/m^2 and the weighted average carcass densities for Zone 2 ranged from to 0.06 to 2.38 kg/m^2. These ranges bracket the Washington carcass density target level, but they are so broad that the comparison is of limited value.

The Washington State target level for phosphorus concentration is 3 to 5 µg/L. This range exceeds the maximum estimate for phosphorus increases that would be expected from salmon escapement and spawning in either Zone 1 or Zone 2 (Table 5.3-3). Note, however, that while the estimates in Table 5.3-3 are for increases in concentration, the Washington State targets are for final concentrations. The comparison, therefore, is of different variables and is of limited value. Because, as noted in Section 5.3.4, it was not possible to estimate actual ambient concentrations of phosphorus in the upstream tributaries from the available data, the final concentrations could not be estimated.

At first glance, the results of the comparisons with target levels based on carcass densities appear to conflict with those based on the phosphorus concentrations. The target levels fall within the ranges of carcass density estimates for Zones 1 and 2, whereas phosphorus concentration target levels exceed the Zone 1 and 2 ranges. The reason for this discrepancy is that the carcass density estimates are directly related to estimates of spawning habitat availability, while the phosphorus (and other nutrient) concentrations are related both to the estimates of spawning habitat availability (from which the nutrient loadings are derived) and to the estimate for total reservoir inflow. As described in Section 5.3, the use of total inflow to compute nutrient concentrations results in underestimating the concentrations, particularly for Zone 1.

6.0 CONCLUSIONS

This study used estimates of spawning habitat availability in the historical Feather River tributaries upstream of Oroville Reservoir to estimate the potential losses of anadromous salmonid biomass and associated nutrients and organic matter due to construction of the Oroville Facilities. The estimated potential losses of nutrients and organic matter are substantial, but the significance of the losses was difficult to evaluate because of several limitations in the available information, including: imprecision of the estimates for potential spawning densities, insufficiently low detection levels for measured nutrient concentrations in the upstream tributaries, and lack of streamflow data for individual tributaries. In spite of these limitations, however, the report provides useful information for guiding any future efforts to assess the significance of the nutrient and organic matter losses and for developing conservative target levels for potential future PM&Es addressing nutrient conditions in the upstream tributaries.

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